Final Report for RJVA 03-166

IMPACTS OF *LINARIA VULGARIS* AND DISTURBANCE ON NATIVE VEGETATION

Introduction

Non-indigenous species (NIS) are often cited as a major cause of plant extinctions and community change (Mack et al. 2000; Mooney and Cleland 2001; Hooper et al. 2005). There is still debate, however, about the relative importance of NIS compared to anthropogenic factors (Gurevitch and Padilla 2004; MacDougall and Turkington 2005) and disturbance in general. NIS can locally replace existing species, creating a structurally less complex plant community (Huenneke et al. 1990; Lavergne et al. 1999; Lambrinos 2000) while disturbance serves as a major force structuring plant communities (Gleason 1926; Connell 1978; Huston 1979; Pickett and White 1985).

Reported impacts of NIS on native plant communities are broad, including loss of native vegetation, reduced recruitment and growth rates of endemic plants and reduced biodiversity, as illustrated by the following examples. Non-native grasses such as cheatgrass (*Bromus tectorum*) have replaced native vegetation and altered the fire cycle in western United States deserts and shrublands (D'Antonio and Vitousek 1992). Seedling recruitment of a California endemic, Antioch Dunes evening primrose (*Oenothera deltoids*), was limited by the presence of a non-native grass (Thomson 2005). Similarly, Huenneke and Thompson (1995) found that seedlings and rosettes of the NIS teasel (*Dipsacus sylvestris*) had negative effects on the growth of the rare Mescalero thistle (*Cirsium vinaceum*). In a Mediterranean-type shrubland in California, invasion by jubata grass (*Cortaderia jubata*) created a structurally less complex perennial grassland

that was depauperate of native shrub species (Lambrinos 2000). In contrast to these findings, however, several authors have shown that NIS do not have a major impact on biodiversity (PlantyTabacchi et al. 1996; Lonsdale 1999; Sax et al. 2002; Gurevitch and Padilla 2004).

The effects of disturbance on plant communities are equally important. Disturbance is any discrete event in time, natural or otherwise, that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (Pickett and White 1985). More specifically, in terms of plant growth, disturbance can be thought of as a process that creates bare ground, loose soil, or light gaps which constitute microsites for new plant recruitment (Crawley 1997). Disturbance may also free up resources, reduce competition and create empty niches that other plants, including NIS can occupy (Elton 1958; Hobbs 1989; Rejmanek 1989; Hobbs and Huenneke 1992; Burke and Grime 1996).

It is difficult, however, to separate the effects of disturbance (especially habitat alteration) from those of NIS invasion as the two may be inextricably linked. Often the issue is not NIS causing the decline of native plants, but rather the decline of natives and the proliferation of NIS are both the result of anthropogenic disturbance (Gurevitch and Padilla 2004). These interrelated effects cannot be teased apart through observational studies where there is no control (i.e., no undisturbed but invaded areas for comparison).

Three common metrics for comparing plant communities are relative species abundance (RSA) distributions, species richness and diversity. Relative species abundance distributions, also known as diversity or rank distributions, plot the dominance of a species (as number of individuals or percent cover) against the species rank (in terms

of commonness). This plot provides a continuous distribution from dominant species through intermediate to rare species, and plots can be compared to examine temporal or spatial differences in communities (Whittaker 1965). Species richness is simply the number of different species that are present in an area. Knowing how many species are present is useful, but richness measures provide no information about how evenly species are distributed in the community. Diversity indices incorporate both richness and evenness. Two such diversity measures are the Simpson and the Shannon-Weiner indices. The Simpson index is a measure of the concentration of species in an area and is most influenced by the common species, while the Shannon-Weiner index is a measure of the uncertainty of species presence and is influenced by rare species (Dejong 1975).

This part of the research sought to understand how the NIS *Linaria vulgaris* impacts existing plant communities and how the plant communities respond to disturbances – specifically herbicide, digging, burning and clipping. Each of the metrics described above was used in this chapter to evaluate community differences and community changes initiated by disturbance.

Materials and Methods

Site Descriptions

This study was conducted at four sites within the Gallatin National Forest near West Yellowstone, Montana. The sites included an area that was logged in the mid 1980's (Clearcut), a site that burned in 1988 (Wildfire), a low-lying area adjacent to the South Fork Madison River and Hebgen Lake (Riparian) and a natural meadow (Meadow). These sites are described in detail in Chapter 2.

Plot Establishment

While this part of the research examined the effects of disturbance on the existing plant community, it was part of a larger study which evaluated the effects of disturbance on *L. vulgaris* population dynamics. Therefore, all plots were established within the interior, on the edge, or just outside of patches of *L. vulgaris*. Establishing plots on the edge and just outside of *L. vulgaris* patches made possible the assessment of the plant community with and without the presence of *L. vulgaris*. It should be noted that this study did not assess the effect of *L. vulgaris* on strictly native vegetation, as many of the plots were established in areas that were dominated by other NIS, particularly Kentucky bluegrass (*Poa pratensis*).

At the Clearcut, Wildfire, Riparian and Meadow Sites, there were 53, 53, 35, and 66 plots, respectively. All plots were 0.25 m^2, and were established in June 2004. More information regarding plot establishment is in Chapter 4 and a summary of plot information is provided in Table 4.1.

Experimental Treatments

Treatments included the application of the broadleaf herbicide Picloram (Tordon*K^{TM}) (Herbicide), digging (Dig) to represent disturbance by burrowing animals, burning (Burn), vegetation clipping (Clip) to simulate grazing and no treatment (Control). Treatments were randomly assigned to plots and implemented in June 2004. More information regarding the treatments is presented in Chapter 4.

Plot Monitoring

Plots were monitored in June 2004 before any treatments were implemented. Plots were monitored again in the fall of 2004, and then in spring and fall of 2005 and 2006, and in the spring of 2007. At each monitoring period, the percent cover of each species, as well as percent cover of litter and bare ground was estimated to the nearest one percent for each plot.

Data Analysis

Measures of *L. vulgaris* Impact. Assessing *L. vulgaris* impact on the extant plant community was not directly possible without knowledge of the community before invasion (i.e., did *L. vulgaris* invasion change the community, or did some property of the community such as reduced richness facilitate invasion?). However, the experimental design was set up such that monitoring plots were placed in areas of *L. vulgaris* patches with different stem densities (interior, edge and just outside of patch). Thus, community differences in terms of richness and diversity, with respect to *L. vulgaris* density, were evaluated through ANOVA based on the plot positions. Also species richness and diversity were analyzed as functions of *L. vulgaris* cover through regression.

Measures of Site Differences. Several metrics, including RSA distributions, species richness and diversity and percent cover values were used to assess plant community differences between sites. Relative species abundance distributions for each site, generated in R (version 2.3.1) with the package LabDSV (Roberts 2006), were used to compare species distributions and diversity between sites. Percent cover values from spring 2004 (prior to treatments) were used as the abundance measures for the RSA distributions, and data from all plots within a site – treatment combination were pooled.

Measures of site diversity, including the Simpson and Shannon-Wiener diversity indices, were also calculated in R with the package Vegan (Oksanen et al. 2005), using percent cover via the following formulas:

Simpson Diversity = D = $\sum p_i^2$

Shannon-Weiner Diversity = H = $-\sum[p_i \ln(p_i)]$

where: p_i is the proportion of the individuals in the ith species ($p_i = n_i/N$)
N is the total number of individuals sampled

Diversity values presented are the mean values from all plots at a site and within a given treatment. For the Simpson index, the presented values are 1-D, such that increasing values represent greater diversity.

Species lists, with species ranked by abundance, were compiled for each site using the spring 2004 pre-treatment data. Finally, analysis of variance (ANOVA) was performed to quantify site differences of percent bare ground, percent litter cover and percent plant cover (excluding *L. vulgaris*) within plots, and Tukey-Kramer multiple comparisons were used to examine site differences in these properties (S-PLUS 2000, Mathsoft, Inc.). R code generated for calculating diversity and RSA distributions is included in Appendix C.

Measures of Effects of Treatments on Plant Communities. Plant community changes were assessed by evaluating changes in the RSA distributions (based on log abundance), richness and Simpson's diversity at each site and for each treatment. Ranked species lists were used to track changes in the abundance of individual species prior to, and subsequent to the disturbances. Only data from spring counts were used for calculations because these data provided more reliable species identification and density

results. The fall data were less consistent in terms of species percent cover and even species identification and presence because in some years drought or early frosts caused premature senescence of some species (relative to other years), and therefore could obscure community response differences.

Results

Impacts of *L. vulgaris* on Plant Community

Overall ANOVA showed differences between sites, so individual sites were evaluated separately. ANOVA results indicated that in spring 2004 prior to disturbance there were no significant differences in species richness between inside, edge and outside plots at the Clearcut, Wildfire and Riparian Sites ($P > 0.05$). At the Meadow Site, edge plots had greater richness than outside plots ($P = 0.002$), however, the difference was only one species, and this is accounted for by the fact that *L. vulgaris* was present in edge plots but generally not present in outside plots. ANOVA results also showed that there were no diversity differences between plot positions for the Clearcut and Wildfire Sites ($P > 0.05$). For the Riparian Site, diversity was lower in the interior plots (which were dominated by *L. vulgaris*) than in edge or outside plots ($P = 0.005$) and in the Meadow Site, outside plots (where *L. vulgaris* presence was minimal) had the lowest diversity ($P = 0.03$).

ANOVA indicated significant differences in *L. vulgaris* cover by plot position. At the Clearcut and Wildfire Sites, *L. vulgaris* cover was higher in interior and edge plots than in outside plots ($P = <0.001$). At the Riparian and Meadow Sites, *L. vulgaris* cover was greatest in interior plots, followed by edge and then outside plots ($P < 0.001$).

Linear regression analysis suggested that species richness and diversity were related to *L. vulgaris* cover at some sites. The relationship between richness and *L. vulgaris* cover was positive at the Clearcut Site ($P = 0.04$, $R^2 = 0.08$) and negative at the Wildfire Site ($P = 0.01$, $R^2 = 0.12$). There was no relationship between *L. vulgaris* cover and species richness at the Riparian and Meadow Sites. Species diversity was negatively related to *L. vulgaris* cover at the Riparian Site ($P = 0.01$, $R^2 = 0.17$) and positively related at the Meadow Site ($P < 0.001$, $R^2 = 0.20$). There was no relationship between *L. vulgaris* cover and diversity at the Clearcut and Wildfire Sites.

Analysis of RSA distributions from spring 2004 for the four sites shows differences in species distributions and diversity (Figure 5.1). The Wildfire Site has the highest diversity as indicated by the curve being farthest to the right. The Meadow Site has the lowest as indicated by the placement of the curve to the lower left. All sites had relatively similar "tails" on the RSA curves, indicating a similar number of rare species. The Clearcut, Wildfire, Riparian and Meadow Sites had mean species richness values of 3.9, 5.7, 4.3 and 4.6, respectively (Table 5.1 and Figure 5.2). Note that the richness values obtained from the RSA curves (i.e., species rank) are not site means, but rather represent the sum of all species at the site. Also, species present at less than one percent cover do not register on the RSA plot because log (<1) is a negative number.

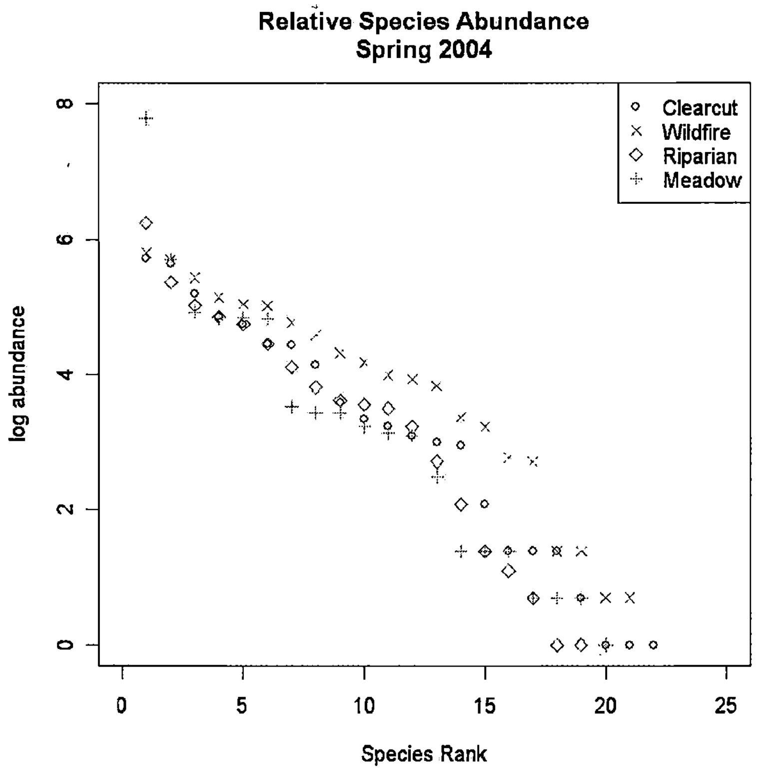

Figure 5.1. Relative species abundance distributions for all sites in spring 2004 (prior to any treatments).

Table 5.1. Richness and diversity values for all sites in spring 2004 (prior to any treatments). Standard deviations are in parentheses.

Site	Richness	Simpson Diversity	Shannon-wiener Diversity
Clearcut	3.9 (1.7)	0.49 (0.20)	0.91 (0.41)
Wildfire	5.7 (1.5)	0.62 (0.16)	1.26 (0.35)
Riparian	4.3 (1.5)	0.52 (0.20)	0.99 (0.42)
Meadow	4.6 (1.3)	0.41 (0.21)	0.81 (0.39)

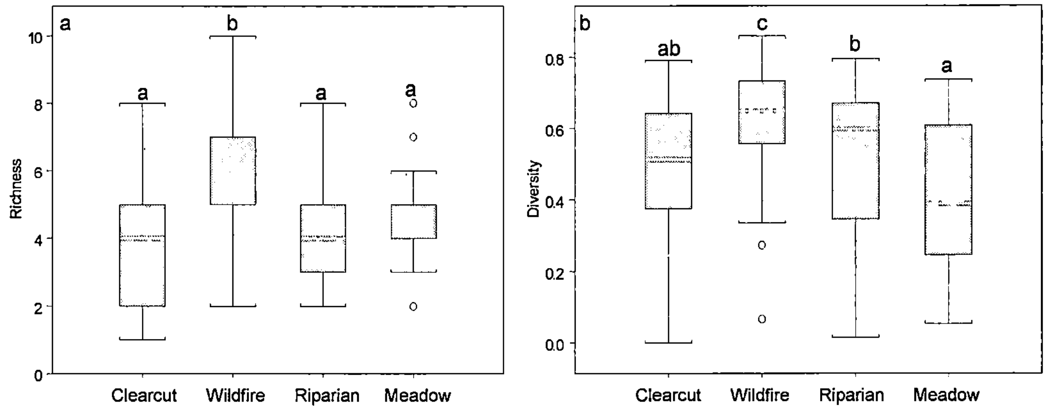

Figure 5.2. Species richness (a) and diversity (b) at each site in spring 2004 (prior to any treatments). Letters indicate significant differences ($\alpha = 0.05$) based on Tukey-Kramer method for multiple comparisons. N = 53, 53, 35 and 66 for Clearcut, Wildfire, Riparian and Meadow Sites, respectively.

The Simpson and Shannon-Wiener diversity indices showed site diversity patterns similar to those obtained from the RSA distributions (Table 5.1). Because the diversity trends are similar between sites, and because the RSA distributions do not indicate a long tail of rare species which would make the Shannon-Wiener index more appropriate, only the Simpson diversity values are presented for subsequent results.

Vegetation community differences were also apparent, based on the species lists. The top ten species, ranked by abundance (percent cover), for each site indicated that the Clearcut and Wildfire Sites had a mix of grasses and forbs, although the most dominant plant species at the Wildfire Site was moss. The Riparian Site was dominated by forbs while the dominant species at the Meadow Site was the non-native grass *Poa pratensis* (Table 5.2).

There are site differences in terms of percent cover of bare soil, vegetative cover and litter cover (Figure 5.3). The most bare soil was at the Wildfire (59 %) and Clearcut (54 %) Sites, followed by the Riparian (43 %) and then the Meadow (5 %) Sites. The pattern was reversed for vegetative cover (excluding *L. vulgaris*), with the Meadow Site (41 %) having significantly more vegetative cover than the Clearcut (10 %) Wildfire (25%) and the Riparian (25 %) Sites. Litter cover was also highest at the Meadow Site (44 %), followed by the Clearcut (22 %) and Riparian (27 %) Sites, and finally the Wildfire Site (9 %).

<u>Effects of Treatments on Community Composition</u>

<u>Clearcut Site</u>. At the Clearcut Site, both species diversity and richness declined after the Herbicide treatment and richness declined after digging (Figures 5.4a and 5.5a). Burning generally did not result in values different from the Control plots. Diversity and richness in herbicide plots increased after the initial decline, but did not return to pre-disturbance levels. Subsequent responses (after two years) to the Dig treatment were not different than in Control plots.

Relative species abundance distributions for all treatments and all years at the Clearcut Site are shown in Figure 5.6. The number as well as abundance of species declined after all treatments. Herbicide and Dig treatments resulted in precipitous drops in the number of species present while the Burn treatment resulted in a slightly lesser

Table 5.2. Ten most abundant species for all sites in spring 2004 (prior to any treatments).

Clearcut	Class[1]	Wildfire	Class	Riparian	Class	Meadow	Class
Pseudoroegneria spicatum	g, p	moss spp.	m, p	*Linaria vulgaris*	f, p	*Poa pratensis*	g, p
Linaria vulgaris	f, p	*Linaria vulgaris*	f, p	*Agoseris glauca*	f, p	*Linaria vulgaris*	f, p
bunchgrass spp.	g, p	*Eriogonum umbellatum*	f, p	*Erigeron speciosus*	f, p	*Erigeron* spp.	f, p
Poa pratensis	g, p	*Poa pratensis*	g, p	*Fragaria virginiana*	f, p	*Geranium viscosissimum*	f, p
Eriogonum umbellatum	f, p	*Collinsia parviflora*	f, a	*Carex* spp.	s, p	*Maianthemum stellatum*	f, p
Agoseris glauca	f, p	*Agoseris glauca*	f, p	*Achillea millefolium*	f, p	*Aster ciliolatus*	f, p
Antennaria microphylla	f, p	*Lupinus argenteus*	f, p	*Taraxacum officinale*	f, p	*Achillea millefolium*	f, p
Collinsia parviflora	f, a	*Carex* spp.	s, p	moss spp.	m, p	*Aster occidentalis*	f, p
Phlox spp.	f, p	*Elymus elymoides*	g, p	*Arnica* spp.	f, p	*Trifolium longipes*	f, p
Elymus elymoides	g, p	*Brassicaceae* spp.	f, p	*Collinsia parviflora*	f, a	*Carex* spp.	s, p

[1]g=grass, f=forb, m=moss, s=sedge, a=annual, p=perennial

decline. The number and abundance of species in the Burn treatment has increased over time, with spring 2007 numbers approaching the original ones, but the values have changed little for the Herbicide and Dig treatments.

The plant community responded differently to the different treatments. In the first year after treatment (spring 2005), herbicide application resulted in a shift from a grass (*P. spicatum* RSA = 4.01) and forb (*L. vulgaris* RSA = 3.93 and *E. umbellatum* RSA = 3.91) dominated community to one dominated by grasses (RSA of all grasses = 13.3 while RSA of all forbs = 1.61). Recovery was fairly rapid, however, with the forb *L. vulgaris* (RSA = 4.54) becoming dominant two years (spring 2006) after treatment, and other forbs including *A. glauca* (RSA = 1.79) and the annual plant *C. parviflora* (RSA = 0.69) appearing in the third year (spring 2007). The Dig treatment changed the community from a rich one (14 species) of mixed grasses (combined RSA = 11.94) and forbs (combined RSA = 19.15) to one containing just three forbs in spring 2005: *L. vulgaris* (RSA = 3.43), *A. ciliolatus* (RSA = 1.10) and *E. speciosus* (RSA = 0.69). This community shift persisted throughout the study period and only a few additional forbs (*A. glauca* RSA = 3.58 and *C. parviflora* RSA = 1.95) and a Carex species (RSA = 1.10) were present by spring 2007. Changes in Burn plots were similar to changes in the Control plots. Complete species lists with RSA values for each treatment and time are included in Appendix D.

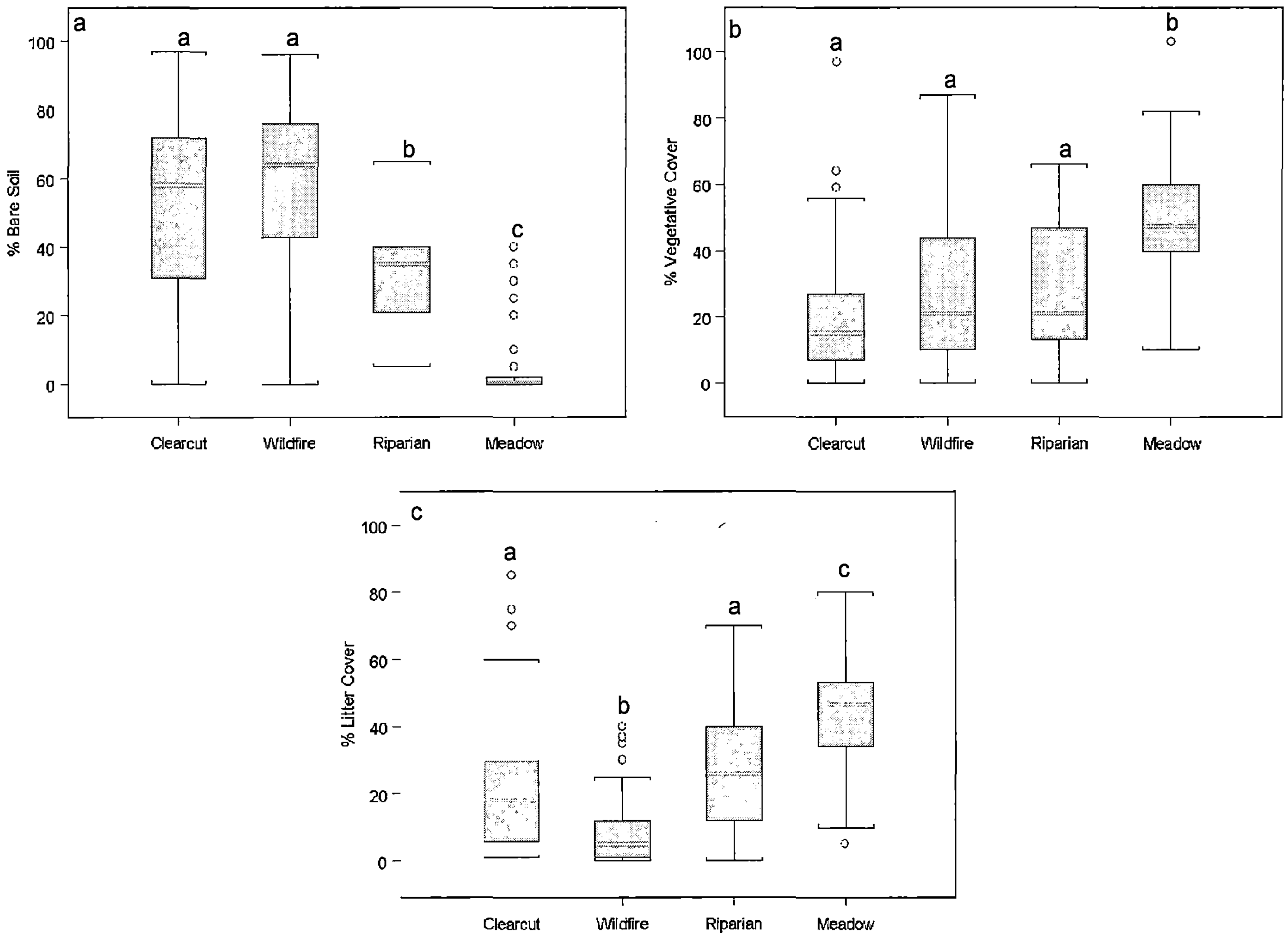

Figure 5.3. Spring 2004 values for % bare soil (a), % vegetative cover (b) and % litter cover (c) for all sites. Data are prior to any treatments at the sites. Box plots show median (central line of box, 50% of data (grey box), 95% of data (bars) and outliers (circles). Letters indicate significant differences (α=0.05) using Tukey-Kramer method for multiple comparisons. N = 53, 53, 35 and 66 for Clearcut, Wildfire, Riparian and Meadow Sites, respectively.

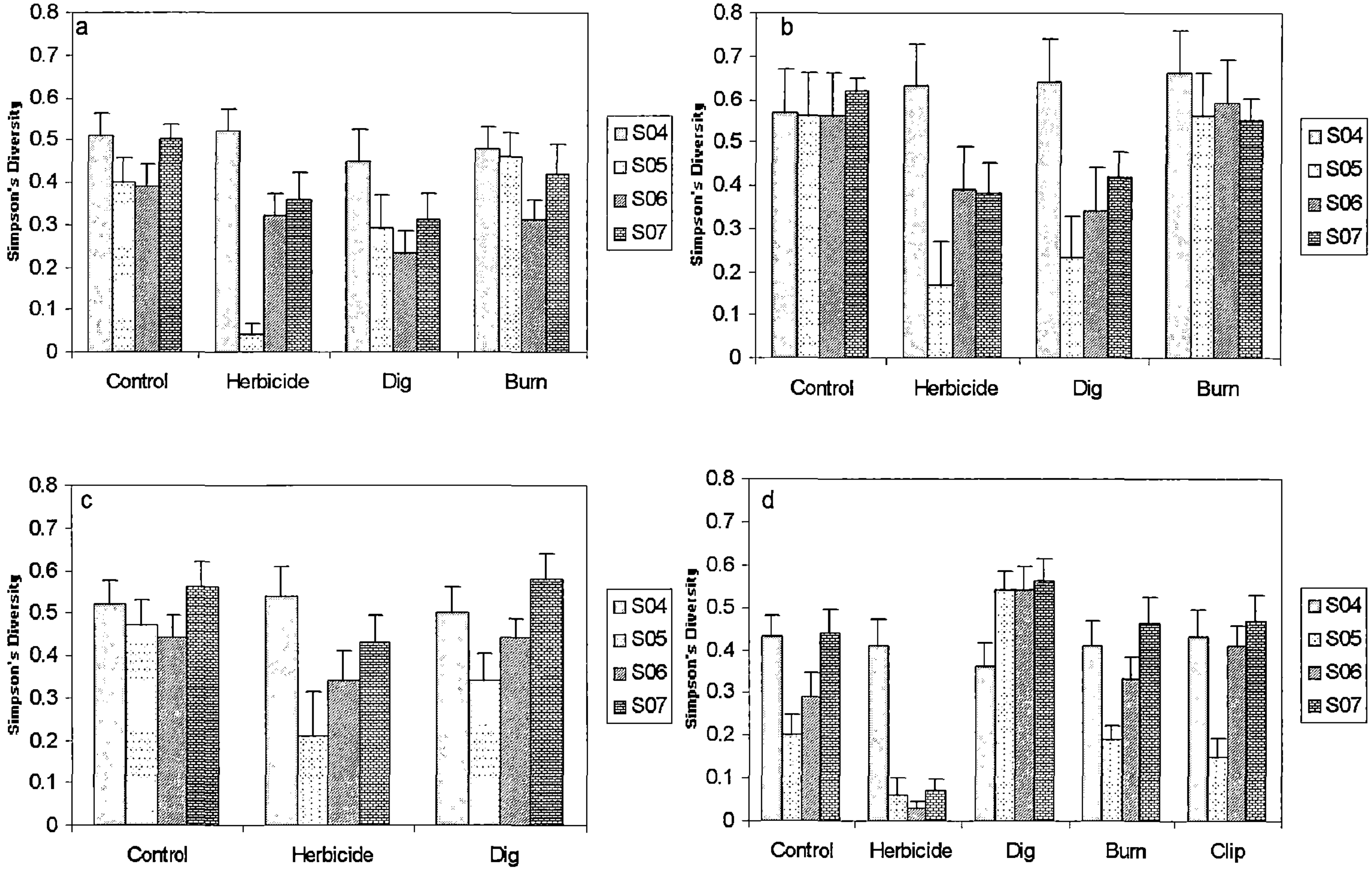

Figure 5.4. Simpson's diversity at (a) Clearcut Site, (b) Wildfire Site, (c) Riparian Site and (d) Meadow Site. S04 = spring 2004, S05 = spring 2005, S06 = spring 2006 and S07 = spring 2007. Error bars show standard error. For Clearcut and Wildfire control plots, N = 17. For Riparian control plots, N = 15. For Meadow control plots, N = 18. For other Riparian treatments, N=10. For all other treatments and sites, N = 12.

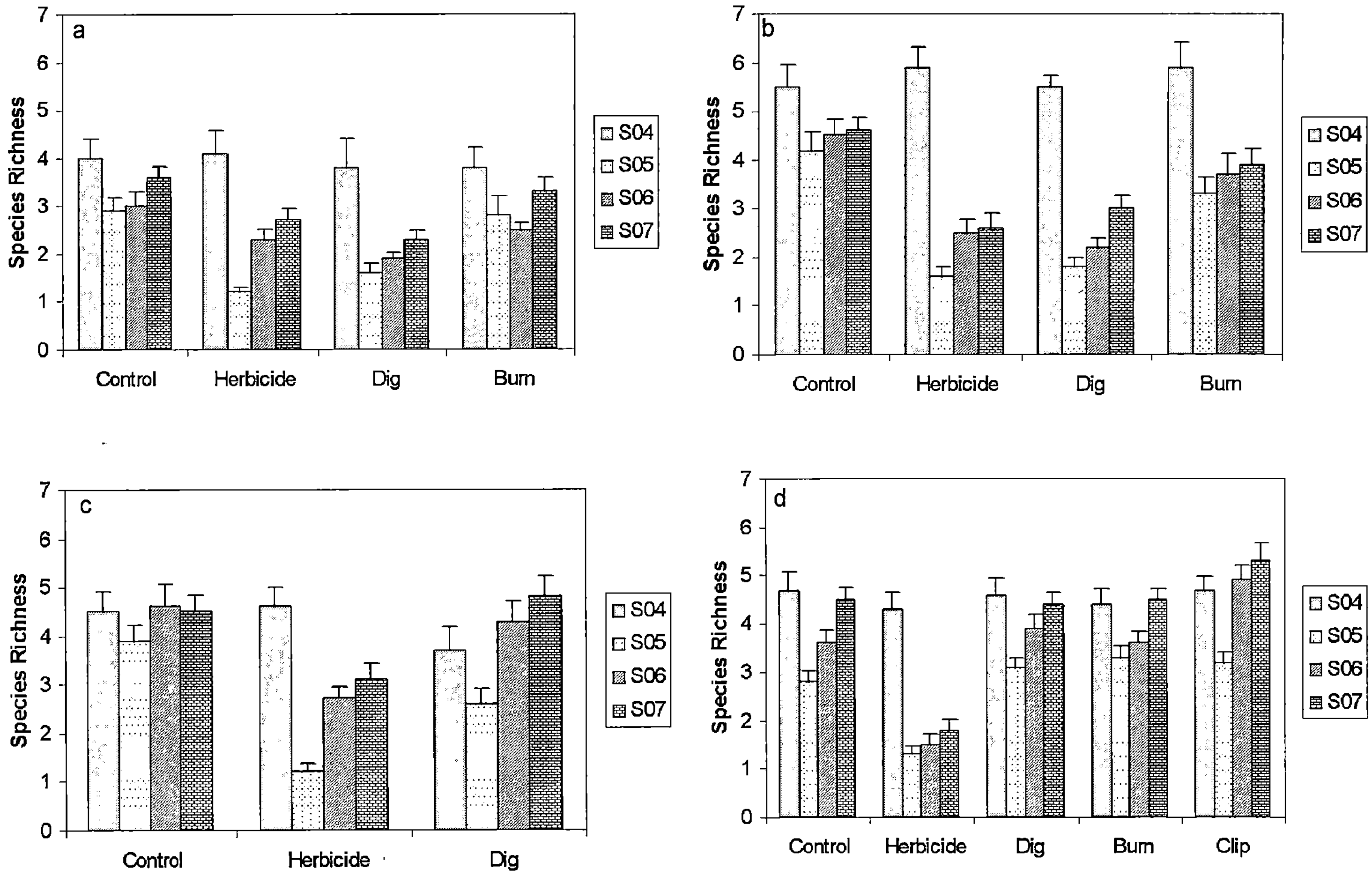

Figure 5.5. Species richness at (a) Clearcut Site, (b) Wildfire Site, (c) Riparian Site and (d) Meadow Site. S04 = spring 2004, S05 = spring 2005, S06 = spring 2006 and S07 = spring 2007. Error bars show standard error. For Clearcut and Wildfire control plots, N = 17. For Riparian control plots, N = 15. For Meadow control plots, N = 18. For other Riparian treatments, N=10. For all other treatments and sites, N = 12.

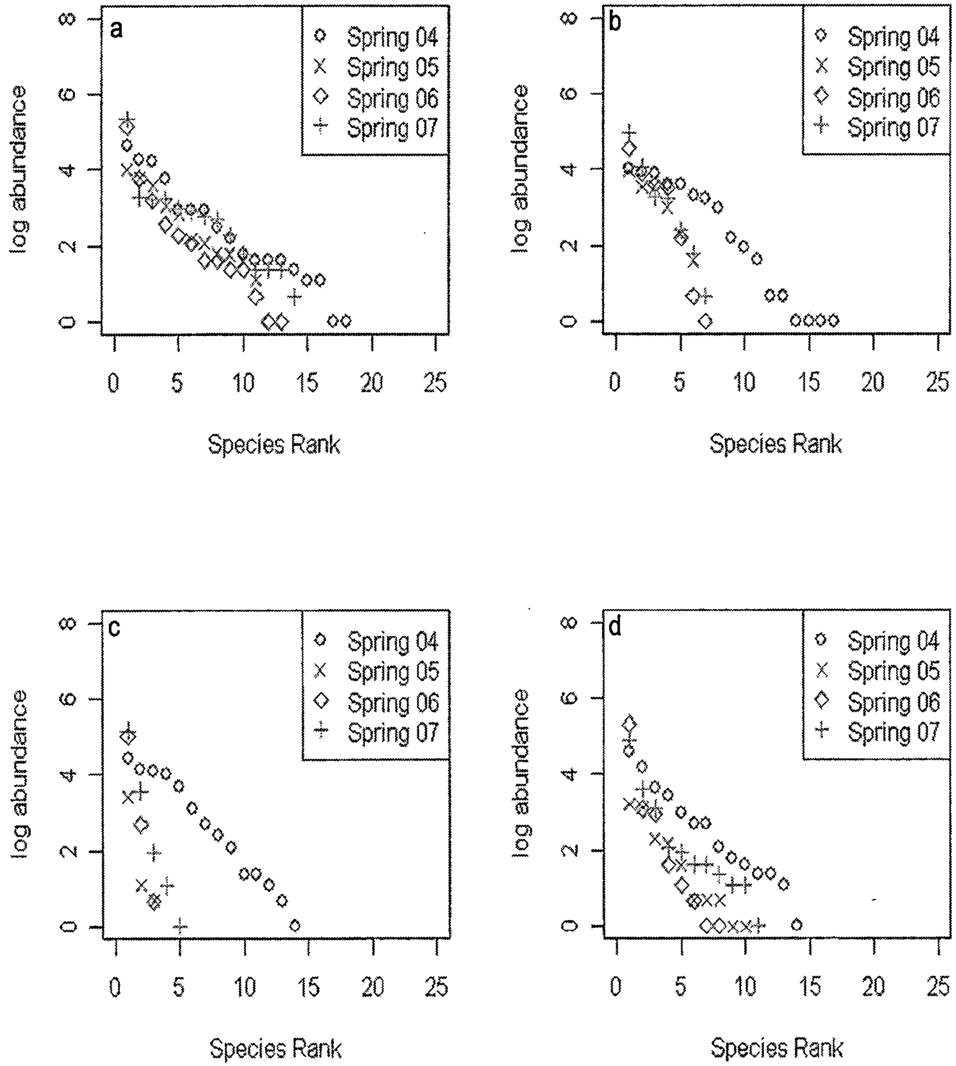

Figure 5.6. Relative species abundance distributions for (a) Control, (b) Herbicide, (c) Dig and (d) Burn treatments at Clearcut Site. The distributions for spring 2004 are prior to any treatments.

Wildfire Site. Herbicide application and digging greatly reduced diversity and richness while burning reduced richness and minimally reduced diversity in the first year after treatment (spring 2005) (Figures 5.4b and 5.5b). Diversity and richness in the Herbicide and Dig plots recovered to just over one half of their original levels in three years, but Burn plots had minimal recovery.

Relative species abundance curves indicated a decline in both species number and abundance following Herbicide and Dig treatments (Figure 5.7), but the RSA distributions for the burned plots were not different from the Control plots. Patterns of diversity recovery at the Wildfire Site were similar to the Clearcut Site with slow recovery in Herbicide and Dig treated plots.

Species composition at the Wildfire Site was changed by the treatments. In spring 2004, prior to herbicide treatment, the most dominant species were a moss (RSA = 4.93), *E. umbellatum* (RSA = 4.45) and *L. vulgaris* (RSA = 4.14). The Herbicide treatment reduced species richness (16 species in spring 2004 to 4 species in spring 2005 in all plots combined) and removed all forbs in spring 2005. In spring 2007, moss (RSA = 5.00) was still the most dominant species, *L. vulgaris* (RSA = 3.87) had returned as the second most dominant species, and three grasses (combined RSA = 10.45) followed. Digging also reduced the number of species (17 in spring 2004 to 4 in spring 2005), but did not change the dominant species, *L. vulgaris* (RSA = 4.13 in spring 2004 and 3.50 in spring 2005). By spring 2007, seven forb species were present with *L. vulgaris* (RSA = 4.63) and *A. glauca* (RSA = 3.66) being most dominant. Burning had a lesser effect on the number of species and the plant community, although some species including *R. tenerrima* (RSA = 1.79) and a *Penstemon* species (RSA = 0.69) that were originally scarcely abundant were

removed from the community. Complete species lists with RSA values for all treatments and times are provided in Appendix D.

Riparian Site. Species diversity and richness at the Riparian Site were initially reduced by the Dig and Herbicide treatments, but then recovered in the second (spring 2006) and third (spring 2007) years (Figures 5.4c and 5.5c). In the case of the Dig treatment, diversity and richness after three years were higher than before treatments, and approximately equal to that of the control. Diversity in herbicide treated plots recovered, but not to pre-treatment levels.

Relative species abundance distributions were also altered after treatments. As shown on Figure 5.8, herbicide application and digging resulted in fewer species present at lower abundances. This is especially true for the Herbicide treatment, where overall species richness (all plots combined) was reduced from 15 to only three species in spring 2005, and by spring 2007, that number only increased to six species. The Dig treatment initially reduced the species richness from 14 to 9 (all plots combined), but richness increased back to the original number by spring 2007, although the abundance of the returning species was still less.

Herbicide treatment effectively removed nearly all forb species (combined RSA in spring 2004 = 24.34) in the first year such that only a small number of the annual *C. parviflora* (RSA = 0.00) were recorded in spring 2005 and *Carex spp.* (RSA = 2.83) was dominant. In subsequent years, plots treated with herbicide became dominated by *L. vulgaris* (RSA = 4.62 in spring 2007) and grasses (combined RSA = 6.78 in spring 2007). Digging had little effect on long-term community composition, with *L. vulgaris* (RSA =

4.44 in spring 2007) and *F. virginiana* (RSA = 3.50 in spring 2007) remaining some of the most dominant species. See Appendix D for complete species lists with RSA values.

Meadow Site. At the Meadow Site, species diversity and richness in plots treated with herbicide declined and remained low through spring 2007 (Figures 5.4d and 5.5d). Species diversity in the Dig plots increased and remained elevated after treatment, but changes in species richness were generally not different from Control plots. Diversity and richness response in Burn and Clip plots were similar to Control plots. The cause of variation in diversity and richness in Control plots is unknown, but is likely related to the time of sampling (see Discussion).

Relative species abundance distribution patterns for the Meadow Site are similar to patterns from the other sites. All treatments, including Control, reduced the number and abundance of species in the first year (Figure 5.9). By spring 2007, species richness and abundance recovered to pre-disturbance levels in all plots except those treated with herbicide, where numbers remained very low. There was no apparent difference between Control, Dig, Burn and Clip treatments in the relative species abundance distributions.

Community response to treatments was varied. Herbicide application changed the plant community from being dominated in spring 2004 by *P. pratensis* (RSA = 6.14) and several forb species including *L. vulgaris* (RSA = 3.97), *Erigeron speciosus* (3.61), *Aster occidentalis* (RSA = 3.40) and *Geranium viscosissimum* (RSA = 3.30) to one dominated almost exclusively by *P. pratensis* (RSA = 5.75 in spring 2007) with the occasional forb (RSA = 3.47 for all forbs combined in spring 2007). The digging treatment, after one year, transformed the community from a very rich one (13 species) dominated by *P. pratensis* (RSA = 6.06 in spring 2004) to a sparsely populated community (5 species) co-

dominated by *L. vulgaris* (RSA = 2.94), *P. pratensis* (RSA = 2.89) and aster species (combined RSA = 3.81) in spring 2005. In subsequent years, more species returned and the community in spring 2007 resembled the original community with *P. pratensis* (RSA = 4.88), *A. occidentalis* (RSA = 3.95) and *L. vulgaris* (RSA = 3.87) being the most dominant species. After the Burn treatment the community changed little and by spring 2007, *P. pratensis* (RSA = 5.68) remained the dominant species, with *L. vulgaris* (RSA = 3.64), *Delphinium glaucum* (RSA = 2.83) and *A. ciliolatus* (RSA = 2.77) being the next most dominant ones. Clipping, simulating grazing, had little effect on community composition and *P. pratensis* (RSA = 5.56), *A. occindentalis* (RSA = 3.5), *L. vulgaris* (RSA = 3.22) and *Maianthemum stellatum* (RSA = 2.64) were generally the most dominant species in spring 2007. Complete species lists with RSA values for all treatments and time periods are included in Appendix D.